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UNITED STATES
NAVAL POSTGRADUATE SCHOOL

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FOREWORD

Computations on which these tables are based were on the U. S. Naval Postgraduate School CRC 102A Digital Computer. The assistance of Professor C. L. Perry of the Mathematics Department is gratefully acknowledged, as is also that of J. Robinson of the Department of Metallurgy and Chemistry.

G. F. K.

TABLES FOR QUASI-EXPONENTIAL DECAY OF EXPLOSIVE SHOCK IN AIR

The conventional representation[1] of an explosive shock in air, on pressure-time coordinates, is as shown in Figure (1). In a formalized and possibly over-simplified manner, this constitutes -

(a) a discontinuous pressure jump from atmospheric to peak pressure,

(b) decay to atmospheric pressure, followed by

(c) a negative pressure pulse of somewhat longer duration.

It is the positive pulse, as described by (a) and (b), that is considered to be the major damaging influence in blast and shock.

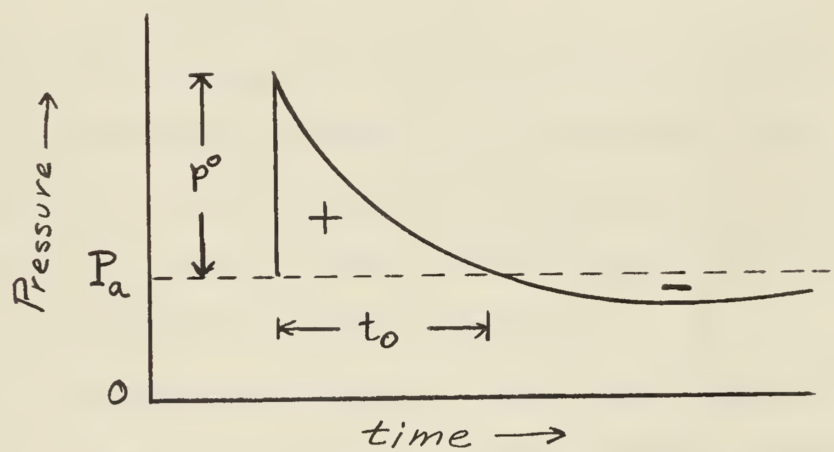

Figure 1.

Conventional Representation of Explosive Shock

Figure (1) indicates that at least three characteristics must be defined in order to describe the positive pulse:

(1) the peak pressure

(2) the duration of the positive pulse, and

(3) the decay characteristic.

Peak pressures are related thermodynamically to other shock properties[2,3]; both they and the duration times have been successfully analyzed[1] in terms of dimensionless parameters and scaling laws. The pattern of decay however is less susceptible to this method of attack. A typical decay characteristic is that given by the modified Friedrichs formula (Ref 1, Page 124)

$$p/P_a = \frac{35}{9}\frac{a}{b}\,(1 + \frac{1}{2}a)$$

where

$$a = \frac{a_o(1-t/t_o)}{1 + a_o(t/t_o)}$$

$$a_o + (1 + \frac{18}{32}\frac{p^o}{P_a}\,b)^{1/2} - 1$$

$$b = r/Y^{1/3}$$

Here p is the shock overpressure at time t, p^o the peak overpressure, P_a the atmospheric pressure, t_o the duration of the positive pulse, and r the distance in feet from an explosion with yield equivalent to Y pounds of TNT. It can be seen that this relation does not readily yield a general solution.

To avoid the complexity of relations of the sort, various empirical equations have been suggested. A simple empirical equation, with one adjustable coefficient to allow for fitting to various circumstances, is as follows:

$$p = p^o(1 - t/t_o)e^{-\alpha t/t_o} \qquad (1)$$

where e is the base of natural logarithms.

The decay indicated by this relation is quasi-exponentional. Coefficient α, a sort of inverse time constant is the decay parameter

selected to make the relation conform to a desired decay. The degree to which conformity with, for example, the Freidrichs equation can be obtained is illustrated in Figure (2). Here the Friedrichs solution[4] for a particular shock with $r/Y^{1/3} = 4.385$, is compared with solutions to equation (1) with decay parameters 2.5 and 3.0 respectively.

It can be observed that the numerical value of the decay parameter α seems to be insensitive to scaling effects, those being accounted for largely by scaled values of parameters p^o and t_o. Also, the decay relation of reference (1) is a special care of equation (1) for which decay parameter α is unity. Another special case is if α equals zero, which corresponds to a triangular pulse.

Table I provides values of the overpressure ratio p/p^o as computed by equation (1). These values were obtained on the Naval Postgraduate School digital computer. The tabulation is presented in a form so that it can be used conveniently as part of the computation of dynamic loading experienced by a structure or member on exposure to shock (see for example references 5 and 6).

The decay parameter α is related to the impulse per unit area, $\int_o^{t_o} p\, dt$, that is characteristic of a given shock. For a shock with known impulse per unit area (and given overpressure and duration of positive pulse) an equivalent decay parameter can be selected by equating the known impulse with that given by equation (1). Decay parameters so selected give a decay curve which closely simulates that of the shock.

Table II gives the impulse corresponding to various values of decay parameter, in terms of the impulse of a triangular pulse having the same peak overpressure and duration. For example the shock decay

corresponding to the Friedrichs relation of Figure (2) provides an impulse per unit area (by graphical integration) of 0.508 times that of a triangular pulse. The corresponding value of decay parameter selected to give the same impulse is, by Table II, 2.5 (closely).

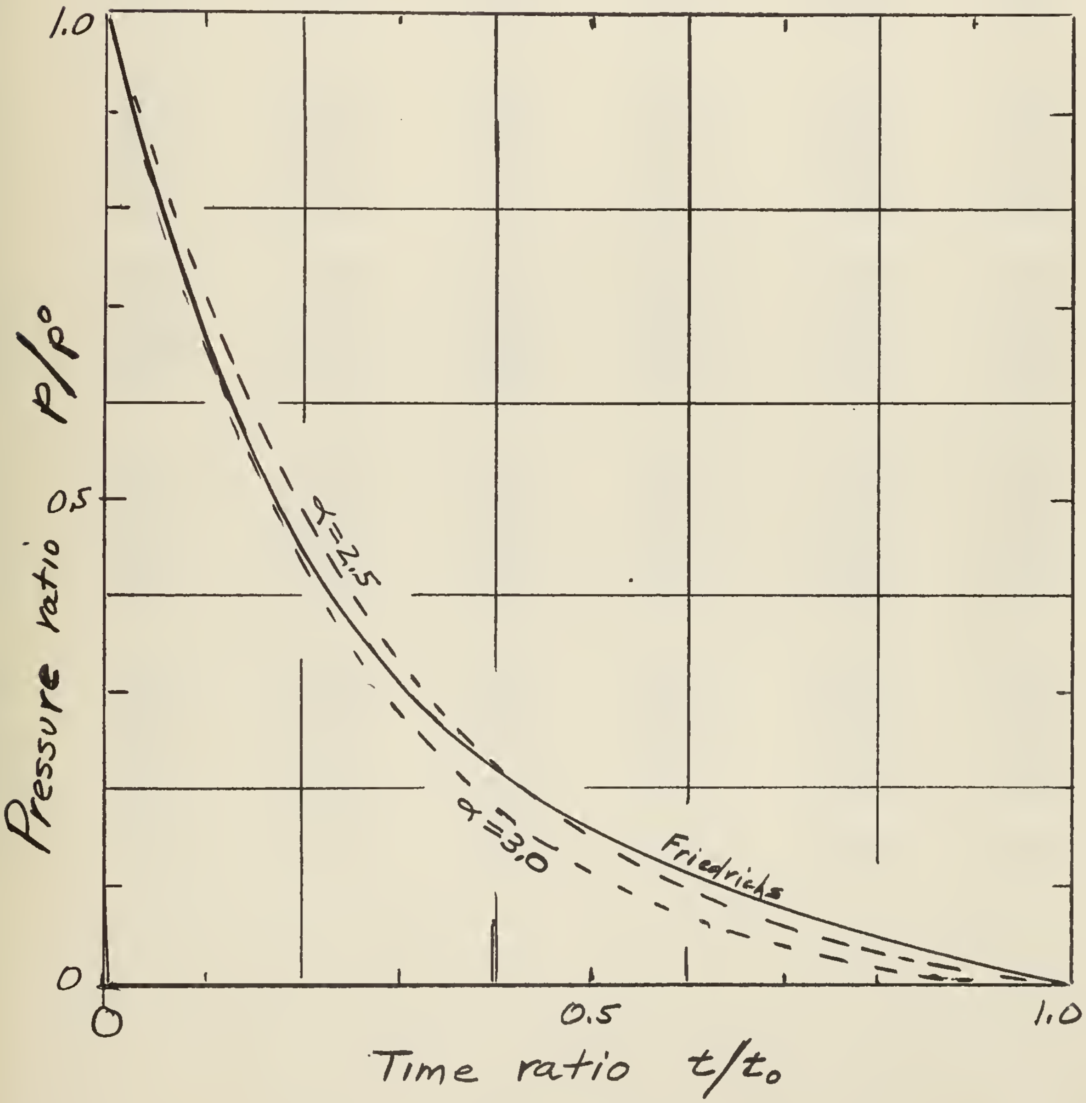

Figure 2.

Pressure Ratios p/p_x

t/t_o	0.0	0.5	1.0	1.5	2.0	2.5	t/t_o
			Decay parameter				
.00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	.00
.01	.9900	.9851	.9801	.9753	.9704	.9656	.01
.02	.9800	.9702	.9606	.9510	.9416	.9322	.02
.03	.9700	.9556	.9413	.9273	.9135	.8999	.03
.04	.9600	.9410	.9224	.9041	.8862	.8686	.04
.05	.9500	.9265	.9037	.8814	.8596	.8384	.05
.06	.9400	.9122	.8853	.8591	.8337	.8091	.06
.07	.9300	.8980	.8671	.8373	.8085	.7807	.07
.08	.9200	.8839	.8493	.8160	.7840	.7532	.08
.09	.9100	.8700	.8317	.7951	.7601	.7266	.09
.10	.9000	.8561	.8144	.7746	.7369	.7009	.10
.11	.8900	.8424	.7973	.7546	.7142	.6760	.11
.12	.8800	.8288	.7805	.7350	.6922	.6519	.12
.13	.8700	.8152	.7639	.7159	.6708	.6286	.13
.14	.8600	.8019	.7476	.6971	.6500	.6060	.14
.15	.8500	.7886	.7316	.6787	.6297	.5842	.15
.16	.8400	.7754	.7158	.6608	.6100	.5631	.16
.17	.8300	.7624	.7002	.6432	.5908	.5426	.17
.18	.8200	.7494	.6849	.6260	.5721	.5229	.18
.19	.8100	.7366	.6698	.6091	.5539	.5037	.19
.20	.8000	.7239	.6550	.5927	.5363	.4852	.20
.21	.7900	.7113	.6404	.5765	.5191	.4673	.21
.22	.7800	.6987	.6260	.5608	.5023	.4500	.22
.23	.7700	.6864	.6118	.5453	.4861	.5333	.23
.24	.7600	.6741	.5978	.5302	.4703	.4171	.24
.25	.7500	.6619	.5841	.5155	.4549	.4014	.25
.26	.7400	.6498	.5706	.5010	.4399	.3863	.26
.27	.7300	.6378	.5573	.4869	.4254	.3717	.27
.28	.7200	.6259	.5442	.4731	.4113	.3575	.28
.29	.7100	.6142	.5313	.4596	.3975	.3439	.29
.30	.7000	.6025	.5186	.4463	.3842	.3307	.30

TABLE I

Pressure Ratios p/p_x

t/t_o	0.0	0.5	1.0	1.5	2.0	2.5	t/t_o
			Decay parameter				
.30	.7000	.6025	.5186	.4463	.3842	.3307	.30
.32	.6800	.5795	.4938	.4208	.3586	.3055	.32
.34	.6600	.5568	.4698	.3963	.3344	.2821	.34
.36	.6400	.5346	.4465	.3730	.3115	.2602	.36
.38	.6200	.5127	.4240	.3506	.2900	.2398	.38
.40	.6000	.4912	.4022	.3293	.2696	.2207	.40
.42	.5800	.4701	.3811	.3089	.2504	.2030	.42
.44	.5600	.4494	.3607	.2894	.2323	.1864	.44
.46	.5400	.4290	.3409	.2708	.2152	.1710	.46
.48	.5200	.4090	.3218	.2531	.1991	.1566	.48
.50	.5000	.3894	.3033	.2362	.1839	.1433	.50
.52	.4800	.3701	.2854	.2200	.1697	.1308	.52
.54	.4600	.3512	.2681	.2046	.1562	.1192	.54
.56	.4400	.3325	.2513	.1900	.1436	.1085	.56
.58	.4200	.3143	.2352	.1760	.1317	.0985	.58
.60	.4000	.2963	.2195	.1626	.1205	.0893	.60
.62	.3800	.2787	.2044	.1499	.1100	.0807	.62
.64	.3600	.2614	.1898	.1378	.1001	.0727	.64
.66	.3400	.2444	.1757	.1263	.0908	.0653	.66
.68	.3200	.2278	.1621	.1154	.0821	.0585	.68
.70	.3000	.2114	.1490	.1050	.0740	.0521	.70
.72	.2800	.1953	.1363	.0951	.0663	.0463	.72
.74	.2600	.1796	.1240	.0857	.0592	.0409	.74
.76	.2400	.1641	.1122	.0768	.0525	.0359	.76
.78	.2200	.1490	.1008	.0683	.0462	.0313	.78
.80	.2000	.1341	.0899	.0602	.0404	.0271	.80
.82	.1800	.1195	.0793	.0526	.0349	.0232	.82
.84	.1600	.1051	.0691	.0454	.0298	.0196	.84
.86	.1400	.0911	.0592	.0385	.0251	.0163	.86
.88	.1200	.0773	.0498	.0321	.0206	.0133	.88
.90	.1000	.0638	.0407	.0259	.0165	.0105	.90
.92	.0800	.0505	.0319	.0201	.0127	.0080	.92
.94	.0600	.0375	.0234	.0146	.0092	.0057	.94
.96	.0400	.0248	.0153	.0095	.0059	.0036	.96
.98	.0200	.0123	.0075	.0046	.0028	.0017	.98

TABLE I
(Continued)

Pressure Ratios p/p_x

t/t_o	Decay parameter 3.0	3.5	4.0	4.5	5.0	5.5	t/t_o
.00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	.00
.01	.9607	.9559	.9512	.9464	.9417	.9370	.01
.02	.9229	.9137	.9047	.8957	.8867	.8779	.02
.03	.8865	.8733	.8603	.8475	.8349	.8225	.03
.04	.8514	.8346	.8181	.8019	.7860	.7704	.04
.05	.8177	.7975	.7778	.7586	.7399	.7216	.05
.06	.7852	.7619	.7394	.7176	.6964	.6758	.06
.07	.7538	.7279	.7029	.6787	.6554	.6328	.07
.08	.7237	.6953	.6681	.6419	.6167	.5925	.08
.09	.6947	.6641	.6349	.6069	.5802	.5547	.09
.10	.6667	.6342	.6033	.5739	.5459	.5193	.10
.11	.6398	.6056	.5732	.5425	.5135	.4860	.11
.12	.6140	.5782	.5445	.5128	.4830	.4548	.12
.13	.5890	.5520	.5172	.4847	.4542	.4256	.13
.14	.5651	.5269	.4912	.4580	.4271	.3982	.14
.15	.5420	.5028	.4665	.4328	.4015	.3725	.15
.16	.5198	.4798	.4429	.4089	.3774	.3484	.16
.17	.4984	.4578	.4205	.3862	.3548	.3258	.17
.18	.4779	.4367	.3991	.3648	.3334	.3047	.18
.19	.4581	.4166	.3788	.3445	.3133	.2849	.19
.20	.4390	.3973	.3595	.3253	.2943	.2663	.20
.21	.4207	.3788	.3410	.3071	.2764	.2489	.21
.22	.4031	.3611	.3235	.2898	.2596	.2326	.22
.23	.3862	.3443	.3069	.2735	.2438	.2173	.23
.24	.3699	.3281	.2910	.2581	.2289	.2030	.24
.25	.3543	.3126	.2759	.2435	.2149	.1896	.25
.26	.3392	.2979	.2616	.2297	.2017	.1771	.26
.27	.3247	.2837	.2479	.2166	.1892	.1653	.27
.28	.3108	.2702	.2349	.2042	.1775	.1544	.28
.29	.2975	.2573	.2226	.1925	.1665	.1441	.29
.30	.2846	.2450	.2108	.1815	.1562	.1344	.30

TABLE I
(Continued)

Pressure Ratios p/p_x

	Decay parameter						
t/t_o	3.0	3.5	4.0	4.5	5.0	5.5	t/t_o
.30	.2846	.2450	.2108	.1815	.1562	.1344	.30
.32	.2604	.2219	.1891	.1611	.1373	.1170	.32
.34	.2380	.2008	.1694	.1429	.1206	.1017	.34
.36	.2173	.1815	.1516	.1267	.1058	.0884	.36
.38	.1983	.1640	.1356	.1121	.0927	.0767	.38
.40	.1807	.1480	.1211	.0992	.0812	.0665	.40
.42	.1645	.1334	.1081	.0876	.0710	.0576	.42
.44	.1496	.1201	.0963	.0773	.0620	.0498	.44
.46	.1359	.1079	.0858	.0681	.0541	.0430	.46
.48	.1232	.0969	.0762	.0600	.0472	.0371	.48
.50	.1116	.0869	.0677	.0527	.0410	.0320	.50
.52	.1009	.0778	.0600	.0462	.0357	.0275	.52
.54	.0910	.0695	.0530	.0405	.0309	.0236	.54
.56	.0820	.0620	.0468	.0354	.0268	.0202	.56
.58	.0737	.0552	.0413	.0309	.0231	.0173	.58
.60	.0661	.0490	.0363	.0269	.0199	.0148	.60
.62	.0592	.0434	.0318	.0233	.0171	.0126	.62
.64	.0528	.0383	.0278	.0202	.0147	.0107	.64
.66	.0469	.0337	.0243	.0174	.0125	.0090	.66
.68	.0416	.0296	.0211	.0150	.0107	.0076	.68
.70	.0367	.0259	.0182	.0129	.0091	.0064	.70
.72	.0323	.0225	.0157	.0110	.0077	.0053	.72
.74	.0282	.0195	.0135	.0093	.0064	.0044	.74
.76	.0245	.0168	.0115	.0079	.0054	.0037	.76
.78	.0212	.0143	.0097	.0066	.0045	.0030	.78
.80	.0181	.0122	.0082	.0055	.0037	.0025	.80
.82	.0154	.0102	.0068	.0045	.0030	.0020	.82
.84	.0129	.0085	.0056	.0037	.0024	.0016	.84
.86	.0106	.0069	.0045	.0029	.0019	.0012	.86
.88	.0086	.0055	.0036	.0023	.0015	.0009	.88
.90	.0067	.0043	.0027	.0017	.0011	.0007	.90
.92	.0051	.0032	.0020	.0013	.0008	.0005	.92
.94	.0036	.0022	.0014	.0009	.0005	.0003	.94
.96	.0022	.0014	.0009	.0005	.0003	.0002	.96
.98	.0011	.0006	.0004	.0002	.0001	.0001	.98

TABLE I
(Continued)

Decay Parameter	$\dfrac{\int_0^{t_o} p\,dt}{1/2\ p^o t_o}$
0.0	1.000
0.5	.852
1.0	.738
1.5	.643
2.0	.568
2.5	.506
3.0	.456
3.5	.413
4.0	.377
4.5	.347
5.0	.321
5.5	.298

TABLE II

Impulse Ratios

SYMBOLS

a	coefficient in Friedrichs equation
b	coefficient in Friedrichs equation
e	base of natural logarithms
p	overpressure (instantaneous)
p^o	peak overpressure
P_a	atmospheric pressure (absolute)
r	distance from explosion, feet
t	time
t_o	duration of positive pulse
Y	explosive yield, pounds of TNT
α	decay parameter, dimensionless

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Tables for quasi-exponential decay of explosive shock in air.